It's All About That Base: Gluteal Function and Activation After Stroke

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Rancho Los Amigos National Rehabilitation Center

What to Expect

- Discussion on improvement of walking after stroke
- Review observational gait analysis and problem-solving for individuals with stroke
- Often misunderstood function of our “Base”
- Supine Hip Extensor Manual Muscle Test
- Activities to increase muscle activation and improve strength
  - To improve walking ability and quality of life after stroke

Ground Reaction Force Vector
Ground Reaction Force Vectors

Weakness
- Avoid torque demand to the muscle
- Allow other muscles to take over
- Find stability and sacrifice forward progression

Hip Problems in Stroke

Past Retract / Decreased Step

Collapse into flexion during Weight Acceptance

Ground Reaction Force Vector

Hip Problems in Stroke

Lateral lean during Single Limb Support
Hip Problems in Stroke
Contralateral Pelvic Drop

Excess Backward Rotation

Hip Problems in Stroke

Patient Example
• Domingo Mateo
• 49 years old
• Husband, father, businessman
• Owns his own mini-market
• Enjoys soccer
• Wants to walk “better”

“I want to walk better”

What does the literature say about improvement in walking after stroke?
Classification of Walking Handicap in the Stroke Population

- Muscle strength, proprioception, walking velocity, functional walking ability at home and in the community
- **Gait speed** was best predictor of walking classification, and participation of mobility in home and the community

  – Perry, Garrett, Gronley, Mulroy – 1995

Meaningful Gait Speed Improvement

- 238 people with stroke
- Comfortable gait speed and mRS scores at 20 and 60 days
- MCID = smallest change that a patient perceives as beneficial
- Estimate MCID > 0.16 m/s more likely to experience a meaningful improvement in disability

  – Tilson et al, 2010 – LEAPS Team

Improvement List:

- Transition to a higher functional level
- Increase speed at least 0.08 - 0.16 m/s

How Do We Increase Speed?

- Increase stride length
- Normal stride is 1.3 meters
- Increase in cadence
- Normal cadence is 115 steps/minute

Improvements in Gait Speed are Meaningful

- Function and quality of life measures (SIS) were significantly higher for those who transitioned to a higher level of ambulation


Classification of Walking Handicap in the Stroke Population

- <0.4 m/s - Household
- >0.4 - <0.8 m/s - Limited community
- >0.8 m/s - Community
- Normal = 1.3 m/s

  – Perry, Garrett, Gronley, Mulroy – 1995
What Happens?

- Increases ground reaction forces
- Increases torque demand
- Weight Acceptance
  - Hip Extensors
  - Quadriceps
- Single Limb Support
  - Hip Abductors
  - Plantar flexors
- Swing Limb Advancement

Normal Skeletons again

How do Individuals Increase Walking Speed after Stroke?

What do we know about walking after experiencing a stroke?

Scientific Literature

- Use of Cluster Analysis for Gait Pattern Classification of Patients in the Early and Late Recovery Phases Following Stroke

Footswitches

— Mulroy et al., 2003
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Motion Analysis

Fine Wire EMG

EMG Muscle Test

• Firing pattern while walking
• Intensity
• Timing
• Quick stretch
  – Duration
  – Intensity

Isometric Torque Testing

• Hip extensors
• Hip abductors
• Knee extensors
• Knee flexors
• Ankle dorsiflexors
• Ankle plantar flexors

– Mulroy et al., 2003

– Mulroy et al., 2003

– Mulroy et al., 2003

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Cluster Analysis

- 4 Distinct groups for initial testing
- 4 Different groups at 6 months
  - Fast
  - Moderate
  - Flexed
  - Extended

--Mulroy et al., 2003

Classification of Gait Patterns after Stroke

Mulroy et al. 2003

Cluster Analysis: Fast

- 67% Normal Speed
- 4° knee flexion TSt
- N knee flexion PSw

--Mulroy et al., 2003

Cluster Analysis: Moderate

- 40% Normal Speed
- 2° Knee hyperext TSt
- 35° knee flexion PSw

--Mulroy et al., 2003

Cluster Analysis: Flexed

- 27% Normal Speed
- 18° Knee flex TSt
- 39° Knee flex PSw

--Mulroy et al., 2003

Cluster Analysis: Extended

- 20% Normal Speed
- 7° Knee hyperext TSt
- 18° Knee flexion PSw

--Mulroy et al., 2003
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Rehab Admission Patterns
- Velocity Mid Swing ankle dorsiflexion
- Mid Stance knee extension

Six Month Patterns
- Velocity
- Mid Swing ankle dorsiflexion
- Mid Stance knee extension
- Pre Swing knee flexion

Rehab Admission Strength
- % Normal Isometric Torque

Six Month Strength
- % Normal Isometric Torque

Cluster Analysis
- Plantar flexors, dorsiflexors weaker in Flexed and Extended groups
- Hip extensors weaker in Flexed
- Knee extensors weaker in Extended

Cluster Analysis
- No difference in spasticity between groups
- Adductor longus most spastic in all groups

–Mulroy et al., 2003
Cluster Analysis

- Soleus intensity higher for Fast
- Cessation of VI delayed for Flexed
- Prolonged Glut Max Flexed and Extended

Cluster Analysis: Summary

- We have distinct groups
- Based on observed gait patterns & speed
- Pattern of weakness differentiates grouping, not spasticity
- Improved gait speed at 6mo related to increased EMG activation and improved strength

Cluster Analysis: Summary

- We have distinct groups
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Improvement List:

- Transition to a higher functional level
- Increase speed at least 0.08 - 0.16 m/s
  - Increased strength key muscles
  - Increased muscle activity key muscles

Recent findings in Kinetics

- Less time in single limb stance on hemi limb
- Step length asymmetry affects forward propulsive force generation

  Balasubramanian et al, 2007

How do Individuals Increase Walking Speed after Stroke?

Improved Gait Speed After Stroke

- "Functional resources to increase gait speed in people with stroke: strategies adopted compared to healthy controls"
- Comfortable walking speed and fast walking
- Higher cadence & shorter stride length in stroke
- Increased work at the hip more than at the ankle
- Results varied considerably


Different Strategies to Increase Speed after Stroke

- Forward propulsion asymmetry between legs
- Some increased speed via non-paretic plantar flexor propulsion
- Some increase speed via paretic leg plantar flexor propulsion

  Allen, Kautz, Neptune, 2014

Forward Propulsion Mechanics

- Anterior-posterior GRF
- Force that acts to propel body forward
- Reduced on hemi side
Breaking & Forward Propulsion Forces

Walking faster after stroke

- Main power burst in hemi & normal walking:
  - Ankle plantar moment at TSt/PSw
  - Hip extension moment at LR
  - Hip abduction moment at MSt
  - Hip flexion moment at PSw

  – Mulroy, Kautz, Sullivan, 2010

Joint Powers

Net Joint Moment
\[ \text{Net Joint Moment} = \text{Generation} - \text{Absorption} \]

Angular Velocity

Winter 1987

Capacity to Increase Walking Speed After Stroke

- Those who were able increased plantar flexor power, and hip flexor power during PSw
- Low functioning patients increased power in the non-hemi limb

  – Jonkers, Delp, Patten 2009

Improved Gait Speed After Stroke

- High response group had more hip extension at Terminal Stance = \text{Trailing Limb Posture}
- Less anterior pelvic tilt
- Greater hip flexion power (net joint moment and angular velocity)
- Soleus EMG higher
- Improved timing of select hip extensors
- Fugl-Meyer score predictor of high vs low responders
  - Low responders increased speed via increased strength of sound side

  – Mulroy, Klassen, Gronley, Eberly, Brown, Sullivan - 2010
Improvement

- Use of Cluster Analysis for gait pattern classification of patients in the early and late recovery phases following stroke
- All patients who improved after 6 months demonstrated increased EMG for all muscles
- Low responders had reduced gluteal and calf EMG

- Mulroy, Gronley, Weiss, Newsam, Perry – 2002

Mechanics After Treatment

- FES plantar flexors/dorsiflexors
- Fast walking on treadmill
  - Trailing limb angle most important contributor to increasing gait speed
  - Plantar flexion moment (internal) at TSt/PSw

- Hsiao, Knarr, et al. 2015, 2016

Recovery vs Compensation

- Lower level patients improved via improved non-hemi limb
- Higher level patients improved via hemi and non-hemi limb.

Improvement List:

- Transition to a higher functional level
- Increase speed 0.08 - 0.16 m/s
  - Large step bilaterally
  - Increased forward propulsion mechanics - hemi side
  - Increased calf & hip extensor EMG & strength
  - Increased hip extension angle at TSt
  - Trailing Limb Posture
  - Increased hip flexion power at PSw/ISw

Why the trailing limb posture?

Influence of Trailing Limb
Influence of Trailing Limb

“All About that Base”
- Gluteal “Base” holds pelvis and trunk stable at loading
- Initiating forward progression
- Gluteal base holds pelvis stable in frontal plane
- Calf “Base” contributes to forward propulsion
- Stable trailing limb positions for passive components of swing

Impaired Trailing Limb
- No heel rise
- Small opposite step
- Inadequate hip ext
- Pelvis dropped out
- External rotation hip:
  - Pelvic hike
  - Abduction
  - Lean laterally
  - Contralateral vault

“I want to walk better”
- To return to work in the mini-market
- To be able to play with my daughter
  - Walk farther
  - Walk faster
- Walk comfortably in confined spaces
- Quick turns, obstacles, etc

Observational Gait Analysis
Initial Contact & Loading Response

- Forward Progression
  - Limited hip flexion
- Shock Absorption
  - Inadequate knee flexion at LR
- Stability
  - Inverted ankle

Mid Stance

- Forward Progression
  - Excess plantar flexion
- Stability
  - Knee hyperextension
  - Contralateral pelvic drop

Terminal Stance

- Forward Progression
  - Inadequate hip extension at TSt
  - Excess plantar flexion
  - No heel rise at TSt
- Stability
  - Knee hyperextension
  - Contralateral pelvic drop

Pre Swing

- Foot Clearance
  - Limited knee flexion
- Limb Advancement
  - Excess dorsiflexion
  - No heel rise

Initial Swing

- Foot Clearance
  - Limited knee flexion
- Limb Advancement
  - Limited hip flexion
Mid Swing
- Foot Clearance
  - Excess plantar flexion
- Limb Advancement
  - Limited hip flexion

Terminal Swing
- Limb Advancement
  - Limited hip flexion
  - Limited knee flexion
- (Stability)
  - Ankle inversion

**Diagnosis:** Right Hemispheric Stroke

**History:** HTN

**Left Lower Extremity:**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Strength</th>
<th>ROM</th>
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</thead>
<tbody>
<tr>
<td>Hip: Flexion</td>
<td>2+</td>
<td>15 - 120</td>
</tr>
<tr>
<td>Hip: Extension</td>
<td>0</td>
<td>0 - 35</td>
</tr>
<tr>
<td>Hip: Abduction</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Knee: Flexion</td>
<td>4/3+</td>
<td>0 – 135</td>
</tr>
<tr>
<td>Knee: Extension</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee: Hyperextension</td>
<td>0</td>
<td>0-10</td>
</tr>
<tr>
<td>Ankle: Dorsiflexion</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Ankle: Plantar Flexion</td>
<td>2</td>
<td>10 – 45</td>
</tr>
<tr>
<td>Subtalar: Inversion</td>
<td>2+</td>
<td>5 – 20</td>
</tr>
<tr>
<td>Subtalar: Eversion</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Tone: Mild increase for calf, adductors with quick stretch
Tactile: Normal
Proprioception: Normal: hip & knee, impaired: ankle & toes
Summary of Stride Characteristics

- Velocity: 12 M/min 15% N
- Cadence: 48 Steps/min 42% N
- Stride Length: 0.54M 35% N

SAGITTAL PLANE MOTION ANALYSIS
PATHOKINESIOLOGY LAB, RANCHO LOS AMIGOS NATIONAL REHABILITATION CENTER

Initial Contact

Early Loading Response

Loading Response
Late Loading Response

Early Mid Stance

Mid Stance

Late Mid Stance

Terminal Stance

No Forward Propulsion Mechanics
- Low force vector
- Force vector very close to ankle joint center
- COM is not in front of the force vector
- There is no trailing limb angle
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Pre Swing

• Force vector moves forward only after opposite foot makes contact

Initial Swing

SAGITTAL PLANE KINETIC ANALYSIS
PATHOKINESIOLOGY LAB, RANCHO LOS AMIGOS NATIONAL REHABILITATION CENTER
Let’s Talk About Strength…
Treatment Focus for Walking Faster

1. Load onto a fully outstretched limb and maintain hip stability
   - Inverted ankle
   - Weak gluteals
2. Progress body weight forward during stance (forward propulsion mechanics)
   - Weak calf
   - Tight Achilles
   - Weak glut med
3. Attain a trailing limb posture
4. Improved hip/knee flexion during swing

All About That Base?

- Weak hip extensors and abductors:
- Reduced loading forces by past-retract and small ipsilateral step length
- Unwilling to progress body weight forward

- Weak calf and hip abductors:
- Unwilling to progress forward in late stance
- Poor trailing limb sets up for impaired swing mechanics: Hip flexor power generation

- Hip extensors
- Hip abductors
- Soleus/Gastroc

Strength is Good

Any Questions?

Jacqueline Perry, MD
Is an AFO Indicated?

Preferred Settings

Conclusion

• All AFOs improved heel first contact and foot clearance in swing.
• Plantar flexion contracture affects performance in an AFO
  – With a contracture: unable to utilize the different brace settings in stance
  – No contracture: an articulating AFO improved gait and a Rigid AFO impeded gait

Why Not Faster Initially in AFO?

• Calf EMG intensity did not decrease when walking in a brace
• Anterior Tibialis EMG did not decrease in articulating AFOs
  – Mild decrease in swing in rigid AFO

AFO Design

Rigid (R)  Plantar Stop (PS)  Dorsi Stop (DS)

Each AFO worn ≥ 2 weeks prior to testing

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Hip Strength & AFO

- 10 subjects with MCA stroke
- Tested in and out of own AFO

Walking speed improved in 4 of 10 subjects in the AFO
Changes in speed, stride length and cadence correlated with hip extension strength ($r=0.63$)
The ability to improve gait speed when wearing an AFO was dependent on hip extension strength

--Weiss et al. 1999

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Hip Strength & AFO

- With increased stability at the ankle the demand of forward progression of the body weight shifted to the hip
- Only those individuals strong enough to handle the increased torque demands from increased stride length or cadence were able to walk faster in their AFO

--Weiss et al. 1999
AFO

- Dorsi stop recommended to stabilize tibia
- Tibial restraint may create the need to lean forward to allow forward progression
- Increases the demand on the hip extensors

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Testing Hip Extensor Strength

- Difficulty attaining prone
- Tight hip flexors
- Hemi shoulder pain

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Supine Hip Extensor Manual Muscle Test


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Jacquelin Perry, MD

- Test Creator
- Polio Clinic
  - spinal fusions
  - hip flexion contracture
  - large abdomen
  - pulmonary problems

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Purpose

To identify a valid and reliable supine testing technique for hip extensors that differentiates 4 levels of strength
Subjects
- Validation and definition
  N = 44 (polio, GB, OA, cauda equina)
  Mean age 52
- Reliability
  N = 16 (post polio syndrome)
  Mean age 51

Validation & Definition
- Supine test performed
- Grade assigned
- Grades confirmed by video
- Maximum isometric torque

Validation & Definition

Supine Test
- Feet over edge
- Press downward
- Tester lifts heel

Grade 5 (Normal)
- Hip locks in neutral

Grade 4 (Good)
Grade 3 (Fair)
- Unable to lock hip
- Strong resistance
- Requires more than 30° before locking hip

Grade 2 (Poor)
- Slight resistance

Biomechanical Rationale
- Greater hip flexion:
  - Fiber length, lever arm
  - Mechanical advantage
  - Increases force production

- Waters 1974

Hip extensor torque

Data Analysis
- One-way ANOVA
- Torque between subjects grouped by muscle test grades
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Isometric Torque

Normalized Torque

Relative Strength

Reliability

Reliability

Supine Hip Extensor Manual Muscle Test

- Two therapists - blinded
- 16 subjects (31 limbs)
- Same day - different times

Reliability

- Kappa statistic - chance adjusted
- 82% agreement - excellent

(Landis and Koch 1977)

- Valid
- Reliable
- Accurately differentiates 4 grades similar to prone test
Clinical Relevance

• Convenient clinical assessment
• Avoids difficulties associated with prone positioning

What We’ve Learned:

• Lift limb higher & hold for several seconds
• Downgrade if need more than 30° to lock hip
• Fold arms across chest

Now What?

• We understand what is needed for improved walking after stroke
• We understand the impact of gluteal weakness in stroke
• We know how to test for weakness
• What should we do to treat?

Treatment Focus #1

• Load fully onto an outstretched limb
  – Inverted ankle
  – Weak gluteals

Best Hip Extensor & Abductor EMG?

• Fine Wire EMG
• Traditional exercises
• Functional activities:
  – Lower Gluteus Max
  – Add Magnus
  – Biceps Femoris
  – Semimembranosus
  – Upper Gluteus Max
  – Gluteus Medius

Fine wire in Ground Plates

Traditional Extension Strengthening

Abduction Exercises
Able-Bodied

Low vs High Fugyl-Meyer: Glut Med

Hip Exercise Summary

• Supine hip abduction poor EMG
• Prone hip abduction better
• Prone hip extension excellent EMG
• Higher functioning —
  — similar to non-stroke population
• Lower functioning —
  — Weight bearing
  — Functionally based
  — Goal oriented

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**Hip EMG on Stairs**

- Increased lower glut max ascending stairs
- Prolonged glut med ascending stairs
- Prolonged upper glut max ascending stairs
- Decreased EMG descending stairs

   - Perry 1975

**Key Concept**

- Forward lean is key to activating gluteals

**Principles of Recovery**

- Prime System with Aerobic Exercise
- High Intensity, High Challenge
- Forced Use Paradigm
- Task Specificity
- Targeted with External Focus
- Positive & Empowering Feedback


**How to Modify Weight-Bearing and Functional Exercises**

- Glut Max EMG - 108% MVC

**Hip Hike**
Hip Hike?

Glut Med Step-Hike

Weight-Bearing, Functional, Targeted

Modified Heel Rise EMG

Running for Max EMG?

Soleus EMG 55% MVC

Soleus EMG 105% MVC

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Running...Too Soon?

Gluteus Maximus: Tri-Planar Muscle
- Extension
- Abduction
- External Rotation

Powers 2015

Transverse Plane Kinetics & Kinematics
- Subtalar eversion
- Internal rotation of tibia
- Internal rotation of femur

Hip Problems in the Ortho World
- Unrestrained internal rotation
  - Valgus stress at knee
- Unrestrained contralateral pelvic drop
  - Varus stress at knee
- Excess lateral lean
  - Valgus stress at knee

Powers 2010

Powers 2015
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Gluteal Med Step-Hike

Calf Strengthening
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Mateo in AFO

- Stride Characteristics
- Motion
- Skeleton
- EMG

EMG Profile in AFO

- Show calf Free Walk
- Show calf in Fast Walk condition
- Show calf in Fast AFO condition
Questions?